Next Steps in the EF – Hadron Colliders

Workshop at the LHC Physics Center (LPC) at FNAL
August 25-28, 2014

Chairs:

Sanjay Padhi (UC San Diego)

Richard Cavanaugh ((UIC)

Boaz Klima (Fermilab, LPC co-coordinator)

Meenakshi Narain (Brown University, LPC co-coordinator)

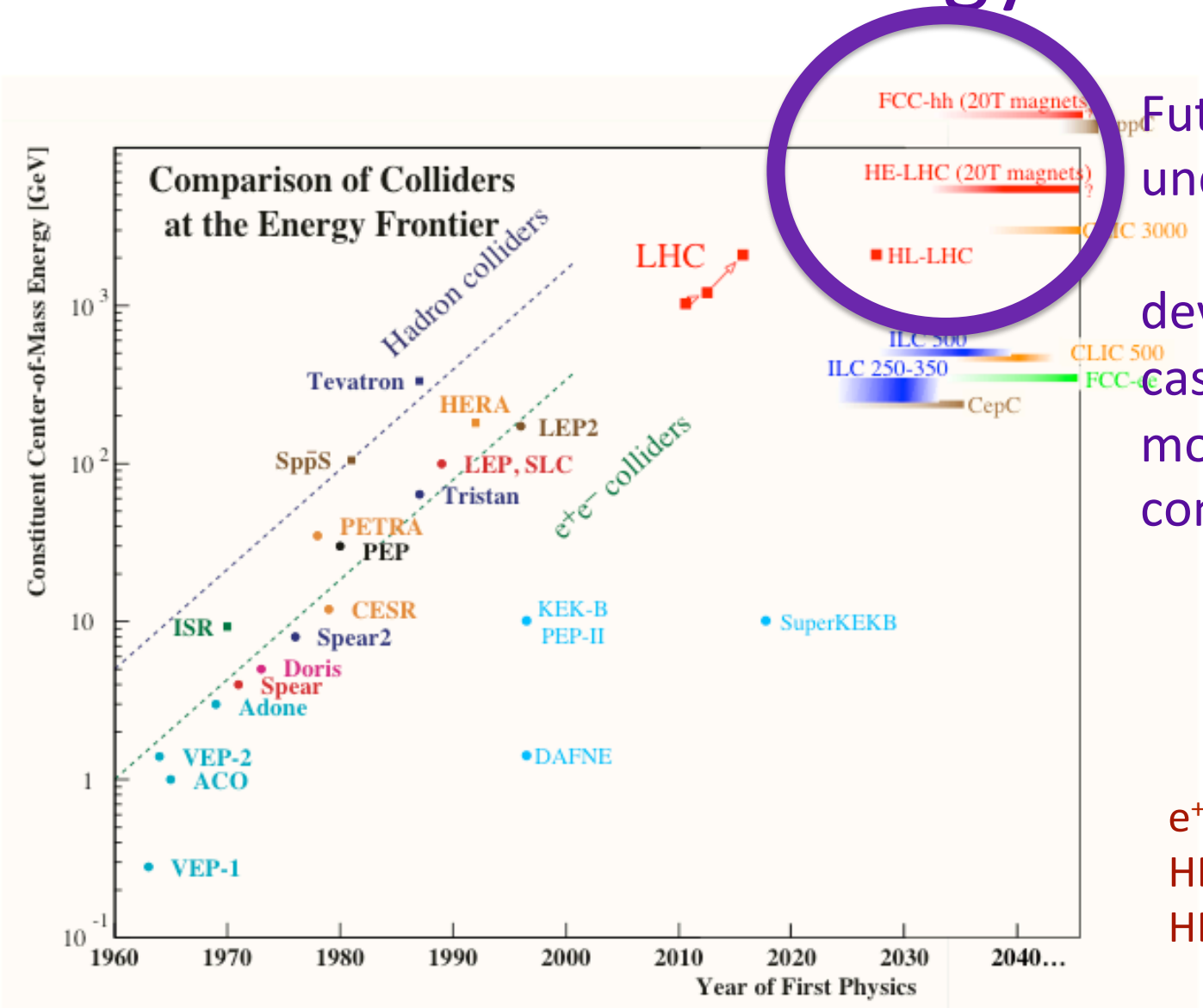
The LPC and Future Colliders

- This workshop is the 3rd in the series hosted by the LPC
  - TLEP workshop (July 2013)
  - 100 TeV collider discussion (Jan 2014)
- In addition we have few contributions to Snowmass physics studies for 100 TeV colliders (SUSY, heavy T', T5/3, excited quarks…)
  - generated SM samples for 100 TeV studies
  - contributing to the simulations for SppC pre-CDR
- Invite you to participate in the future discussions at the LPC and take advantage of the many programs
  - LPC Guests &Visitors Program (for CMS members)
  - LPC "Topic of the Week" (seminars, office hours) (open to all)
  - LPC workshops (such as this one! – open to all)
  - see http://lpc.fnal.gov

Theme and Goals of the workshop

- The aim of this workshop is to bring together physics, instrumentation/detector and accelerator experts to discuss all aspects needed for the next steps in the energy frontier.
- Focus on:
  - The lessons learned with 7 and 8 TeV LHC, physics requirements and subsequent detector technologies for HL-LHC
  - Development of needs for future 100 TeV proton collider.
- In addition, detector technological developments will depend on the physics cases some of which we hope this workshop can provide.
- The goal is to identify synergies and common approaches where further collaboration between various initiatives could be fruitful.

Colliders at the Energy Frontier



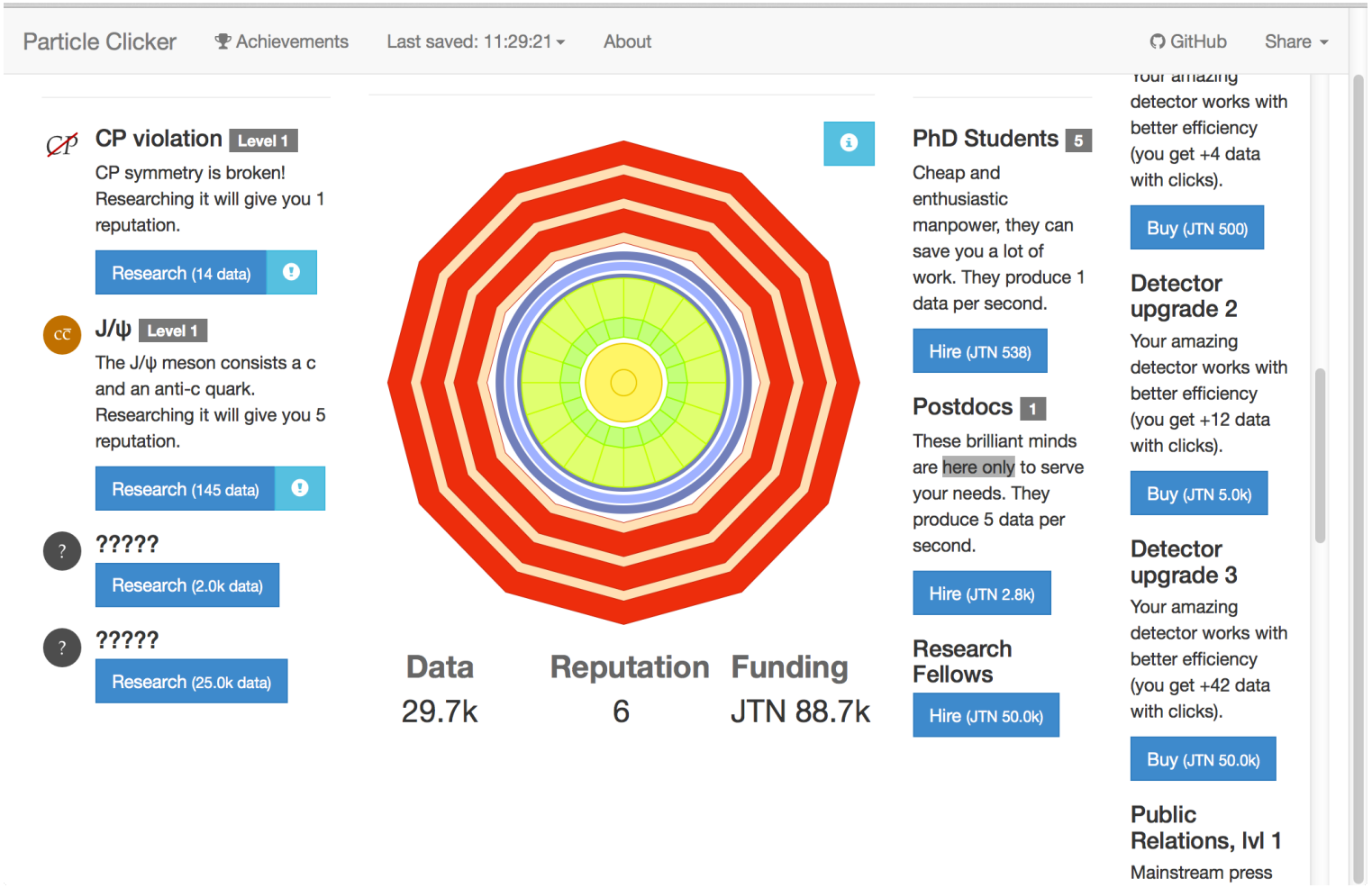
Future pp Facilities under discussion.

develop physics case and then move towards a conceptual design

e^+e^- Linear Colliders
HE e^+e^- Storage Rings
HE pp Colliders

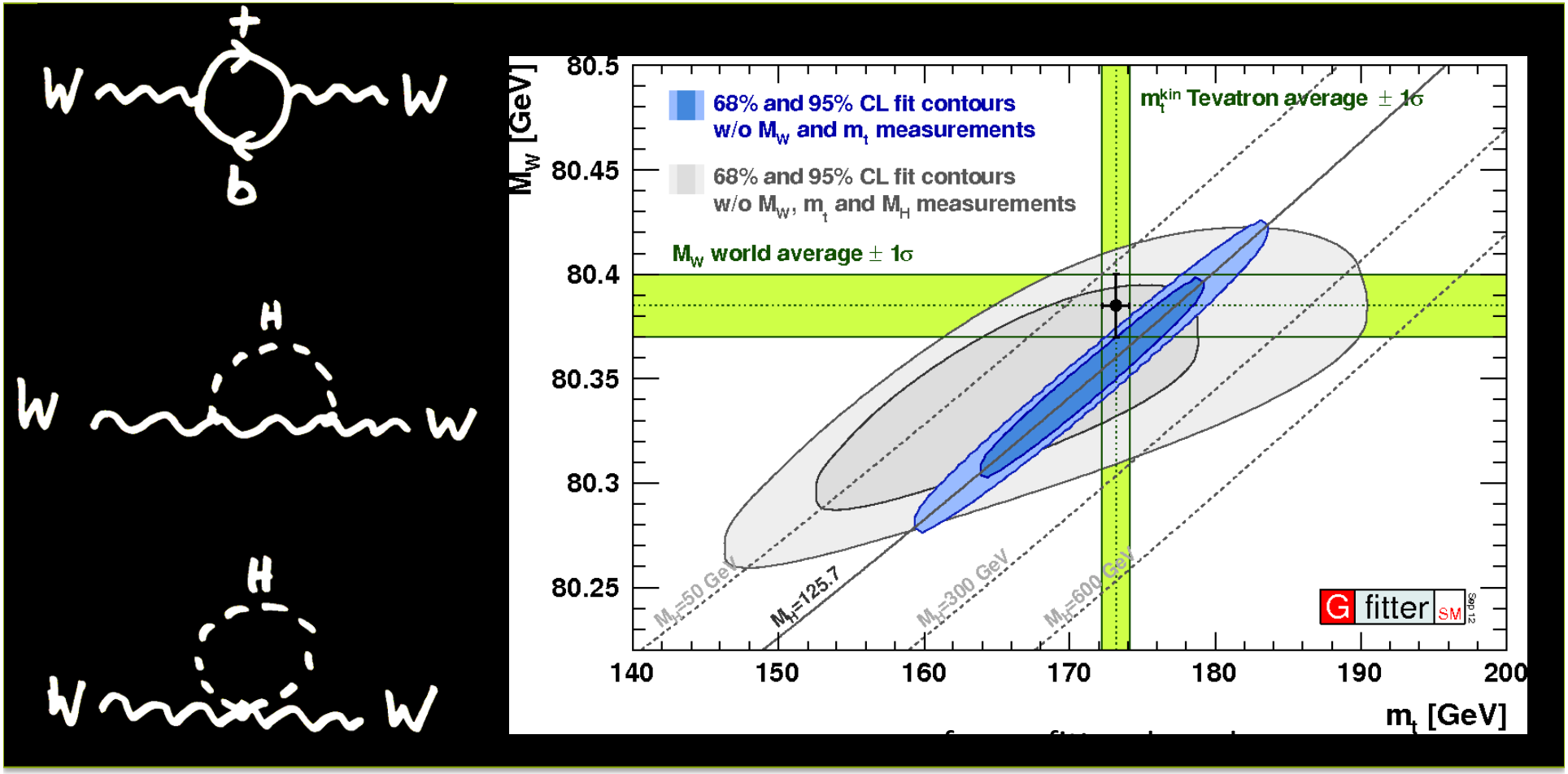
Colliders and Detectors for tommorow

http://particle-clicker.web.cern.ch/particle-clicker/



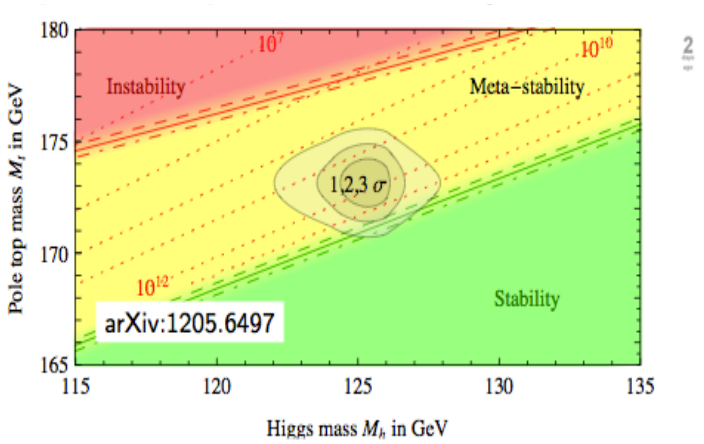
Consistency of SM: a success story

- Higgs, W boson mass and top quark mass



Implications of Low mass Higgs

- The Nature of the Vacuum
  - We are in a highly fine-tuned situation: the vacuum is at the verge of being either stable or metastable!
  - ~1 GeV in either of the two masses is all it takes to tip the scales!
- Perhaps Nature is trying to tell us something here?
  - New Physics inevitable? Which scale/energy ? ~10^{11} GeV or less?
  - Are statements about stability independent of the nature of the new physics ??
- Naturalness? Multiverse?
  - Meso-Tuning? Anthropic Universe? Meso-Anthropic-tuned universe?

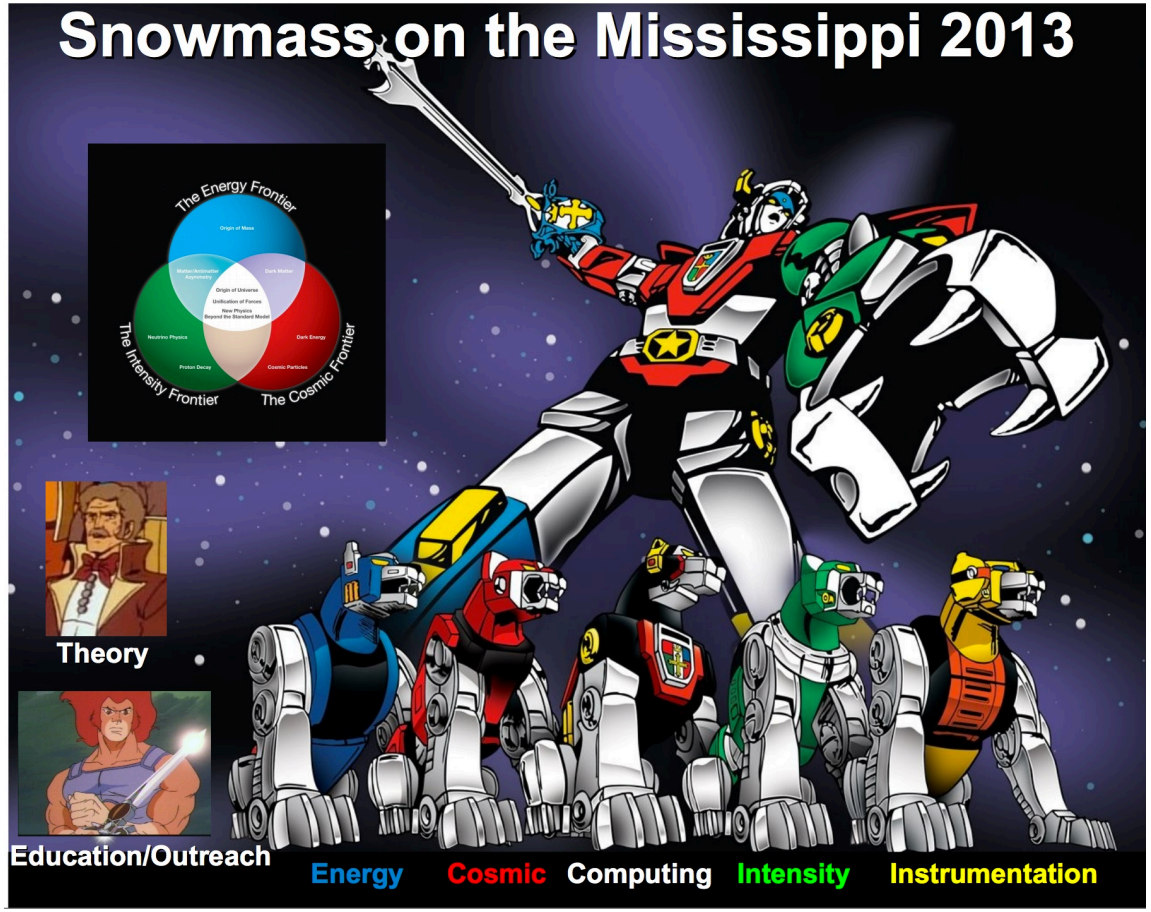


Our Universe meta-stable ?
Will the Universe disappear in a Big Slurp? (NBCNEWS.com)

- Is it THE Standard Model Higgs or a messenger of New Physics ?
- How can we explain a Higgs mass ~ 126 GeV? What stabilizes its mass? New Physics e.g. Supersymmetry?
- What explains the mass pattern of the particles we observe?
- What is Dark Matter and Dark energy?
- Neutrino masses and properties?
- etc..

- Physics Program:
- Properties of the new Higgs boson, precise determination of its characteristics
- High mass reach for new particles and interactions
- Precision measurements
- Rare process

Many Open Questions



FUTURE STRATEGY

European Strategy for Particle Physics

an ambitious post-LHC project

- European Strategy Update on Particle Physics
- May 2013

d) To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. ***CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high energy frontier machines. …***

Support R&D for 100 TeV pp collider

- US: Particle Physics Project Prioritization Panel (P5)
- May 2014

Recommendation 23: …"Support the discipline of accelerator science through advanced accelerator facilities"

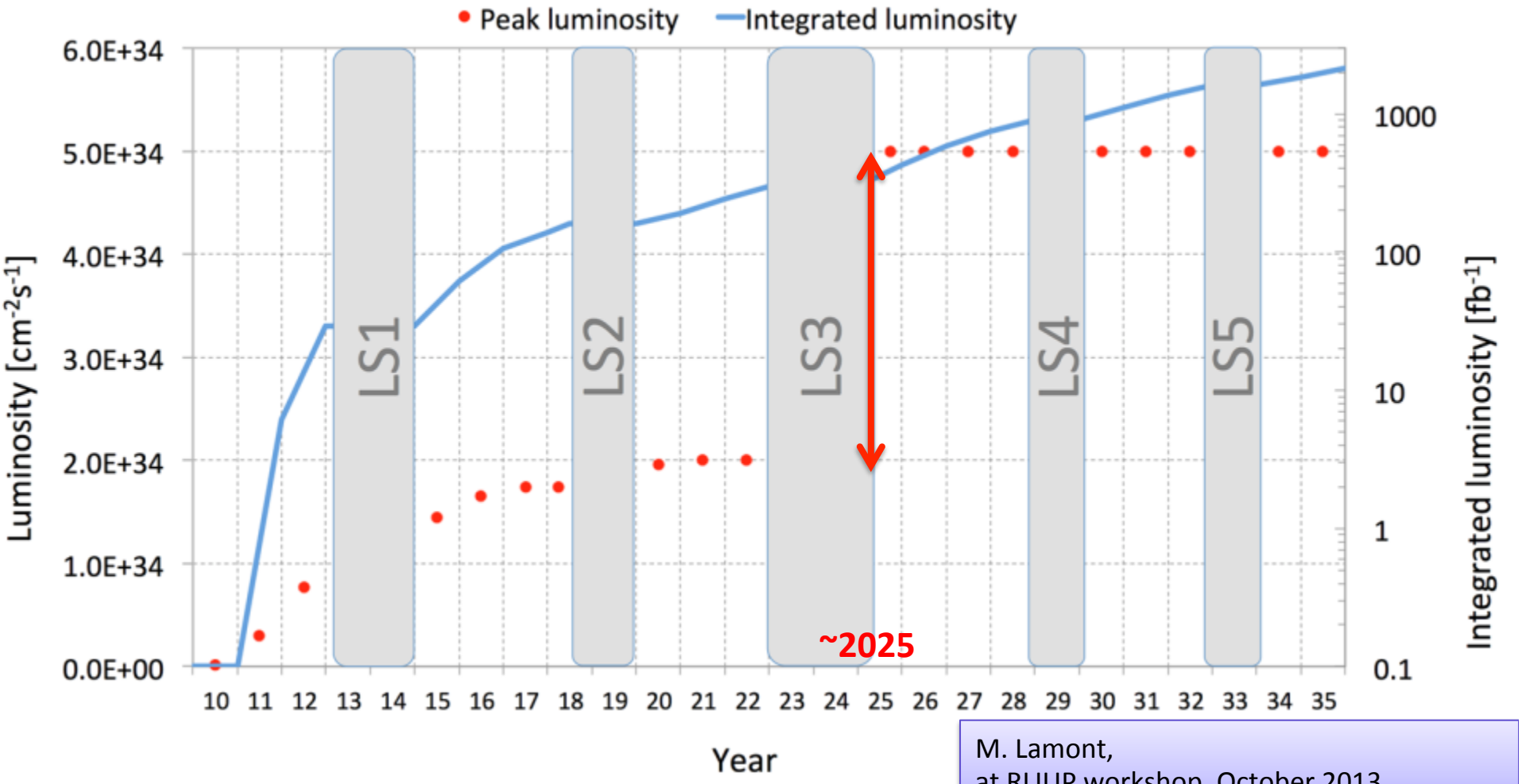
…**A very high-energy proton-proton collider is the most powerful future tool for direct discovery of new particles** and interactions under any scenario of physics results that can be acquired in the P5 time window. **Colliders of energy up to 100 TeV, with a circumference of about 100 km with an option of e+e–**, are presently under study at CERN, in China, and in the U.S. Extensive R&D is required to make such a collider feasible at a reasonable cost. The U.S. is the world leader in R&D on high-field super- conducting magnet technology, which will be a critical enabling technology for such a collider…

Colliders: near and far future

- The fun is just beginning!
- LHC:
  - premium in increasing √s close to 14 TeV
  - High-Luminosity LHC with a factor of 200 more data
    - Good prospects for precision measurements, discovering additional Higgs, and other new particles
- Future plans beyond the LHC:
  - High Enegy LHC @ 33 TeV
  - e+e- Linear Collider start @ 250 GeV
  - a new 80 km ring e+e- @350 GeV
  - pp collider around 100 TeV.

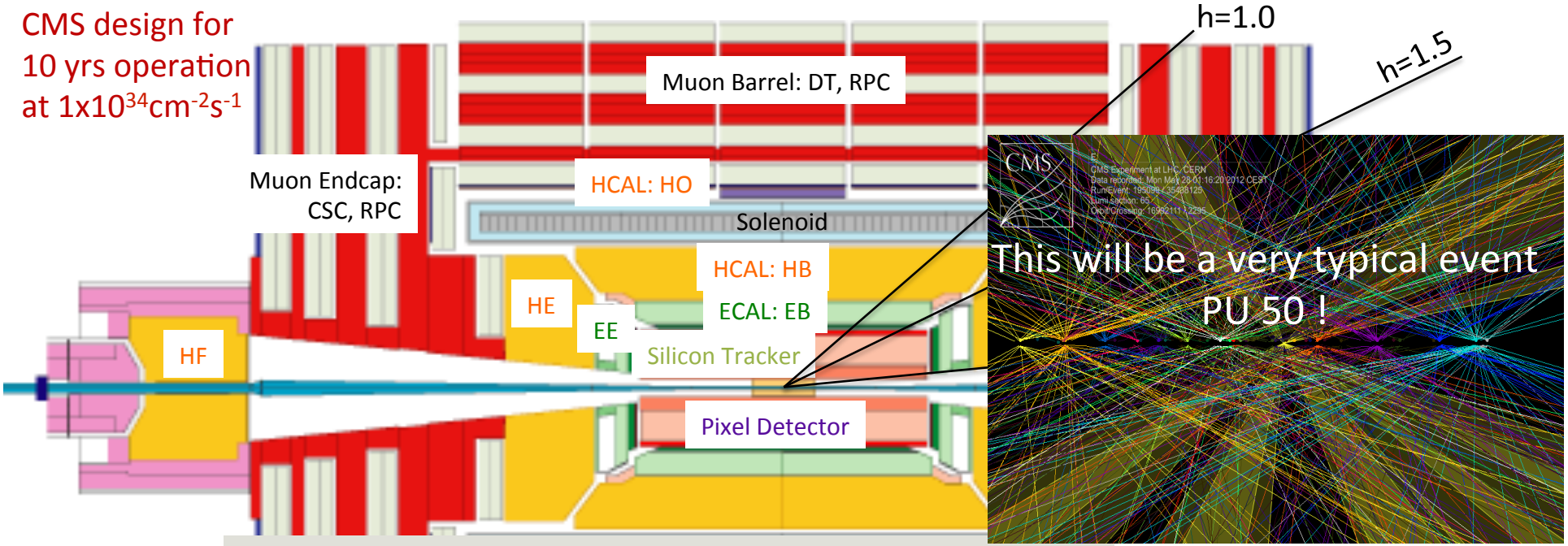
THE LHC LUMINOSITY UPGRADE (HL-LHC)

HL-LHC Luminosity goal



M. Lamont,
at RLIUP workshop, October 2013

CMS design for
10 yrs operation
at 1x10^{34}cm^{-2}s^{-1}



LHC to HL-LHC - The Challeng

<PU> up to 140

Due to radiation damage, LHC detectors will not survive beyond ~500 fb^{-1}

- **Must replace inoperable elements: Tracking detectors, endcap calorimeters**
- **Must upgrade electronics to cope with increased rates (esp. trigger)**

Tracking
More than 220m
76M channels (p
6m long, ~2.2m
Tracking to |h|<

Muon System
Muon tracking in
Barrel: Drift Tube
Endcap: Cathode

tic scintillator
Tiles and WLS fiber
Cerenkov calo.
"tail catcher"

This will be a ver

latency ,100 kHz

: Tracking , Full reco

HL-LHC: Higgs Factory, BS… WK

- HL-LHC (3 ab-[1])
  - 17 M Higgs produced in each experiment
    - ~ 2 million events afte…
  - HL-LHC would be t…
    - With access …
      - H -…
- Becom…
  - …
- Ra…
  - Su… …500 GeV
- Dark Ma… …tures

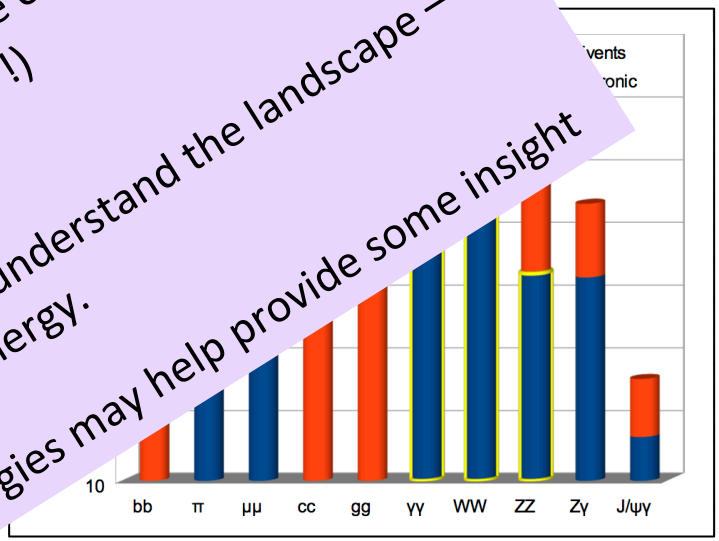
produced

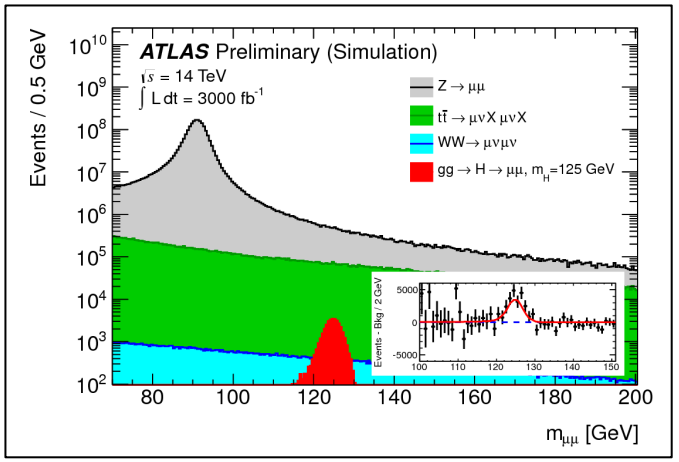
Hopefully we will discover something new
- help determine the scale of new physics – couple of TeV, 10s of TeV?
- (also insight from the precision measurements !)

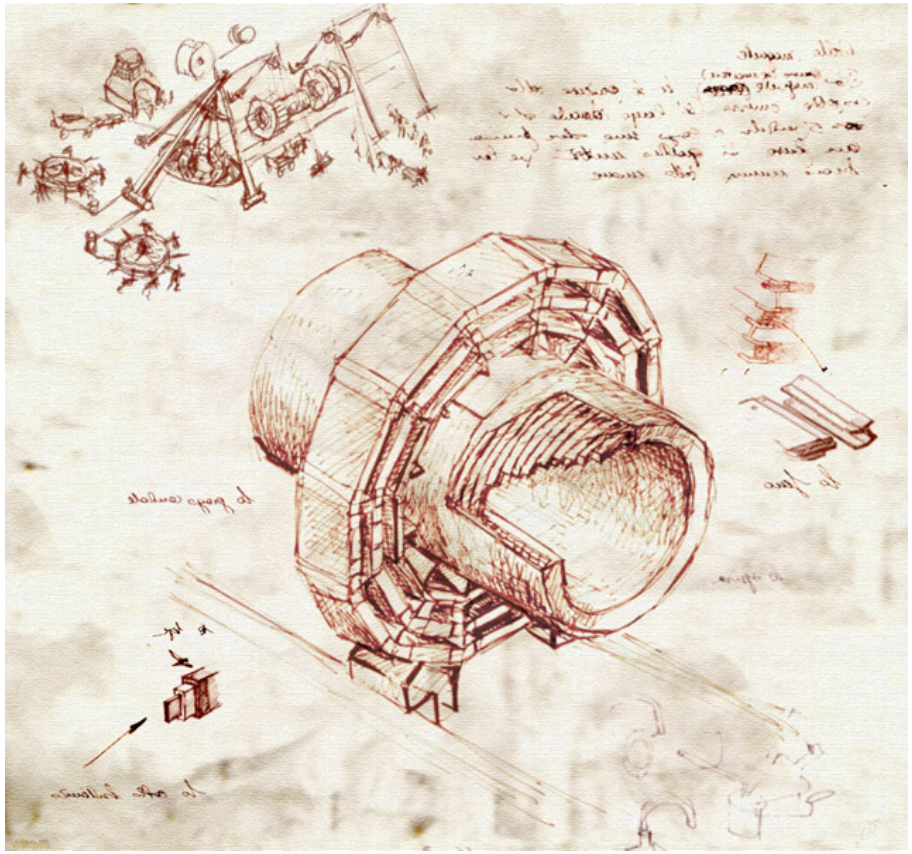
if we discover something new…
- need to measure its properties and fully understand the landscape – →

we need better instruments – higher energy.

if we discover nothing beyond Higgs
- WW scattering at much higher energies may help provide some insight



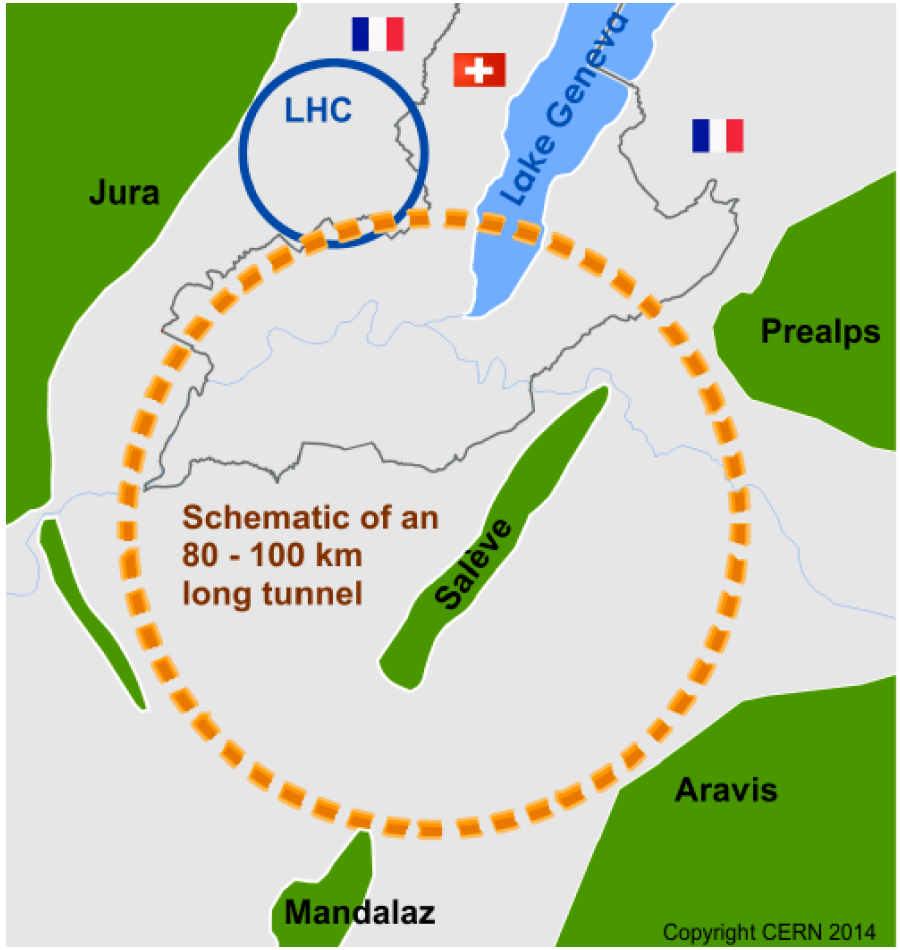




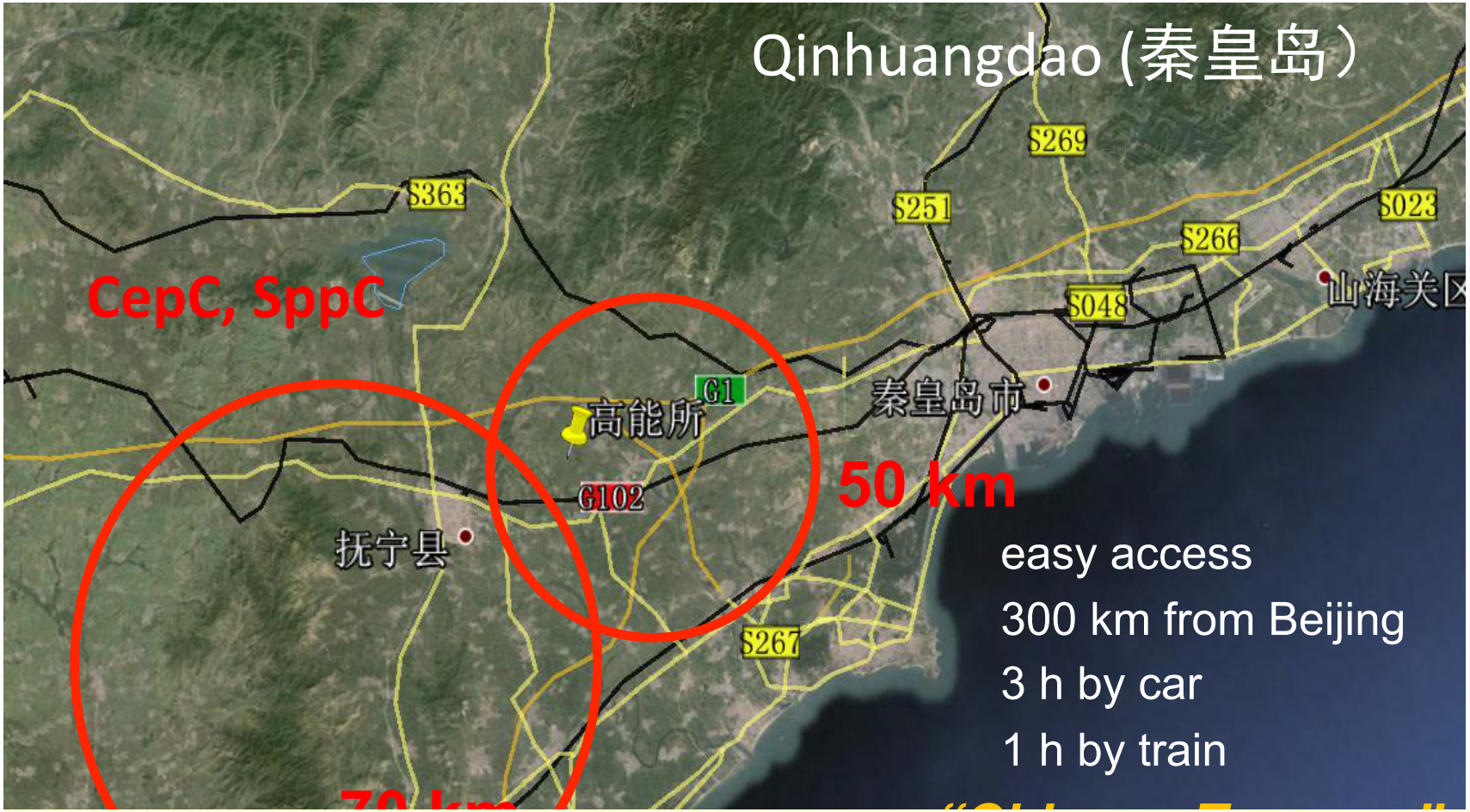
THE NEXT STEPS IN ENERGY FRONTIER

Future Circular Colliders (FCC-hh)

- CERN Initiative: (intermediate step FCC-ee)



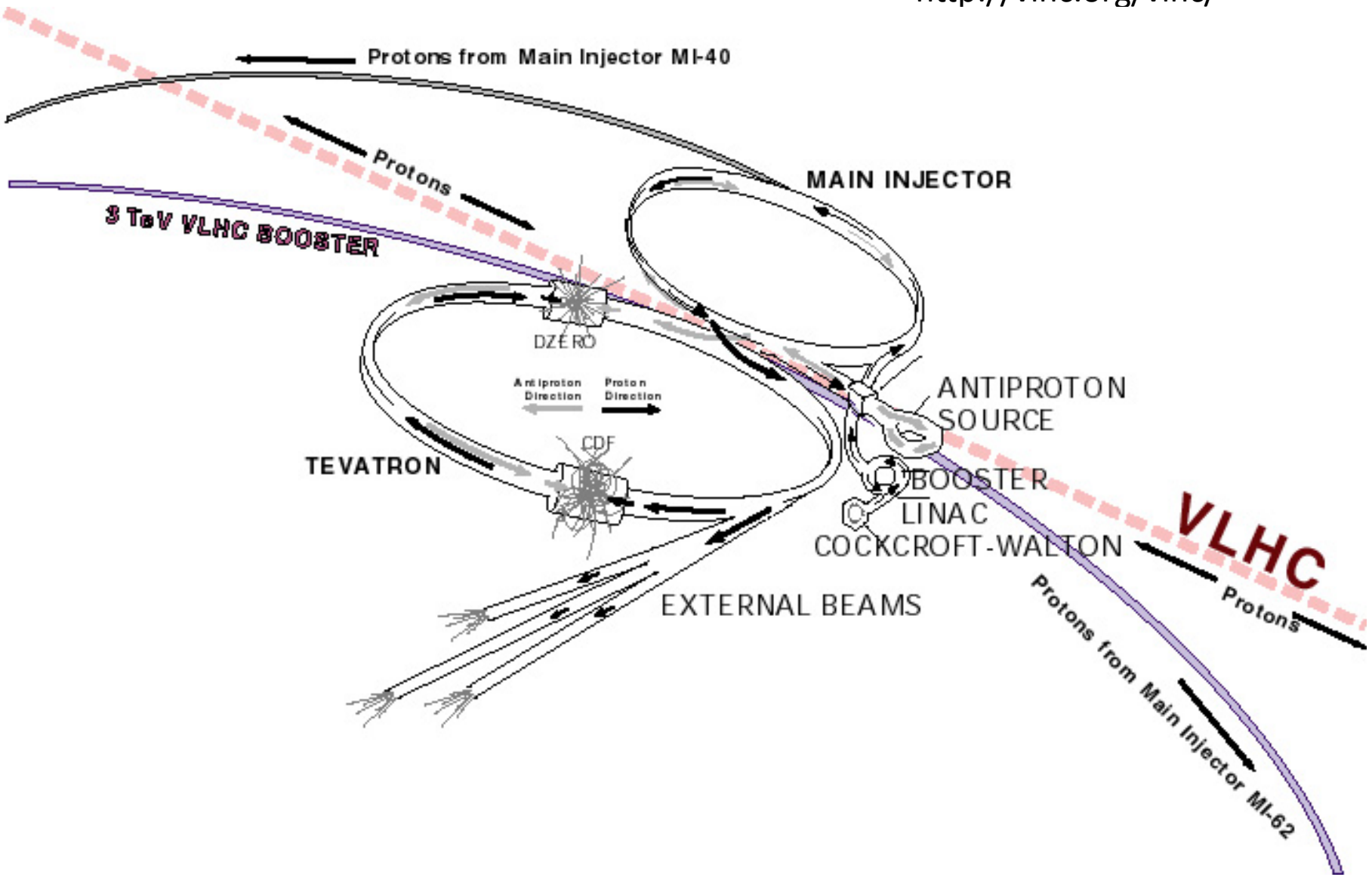
CepC/SppC study (CAS-IHEP), CepC CDR end of 2014, e^+e^- collisions ~2028; *pp* collisions ~2042



- Aim: design completed in 2020; pp collisions ~2042
- A 60-70 km tunnel is very affordable in China NOW!
- Contribute to the world effort

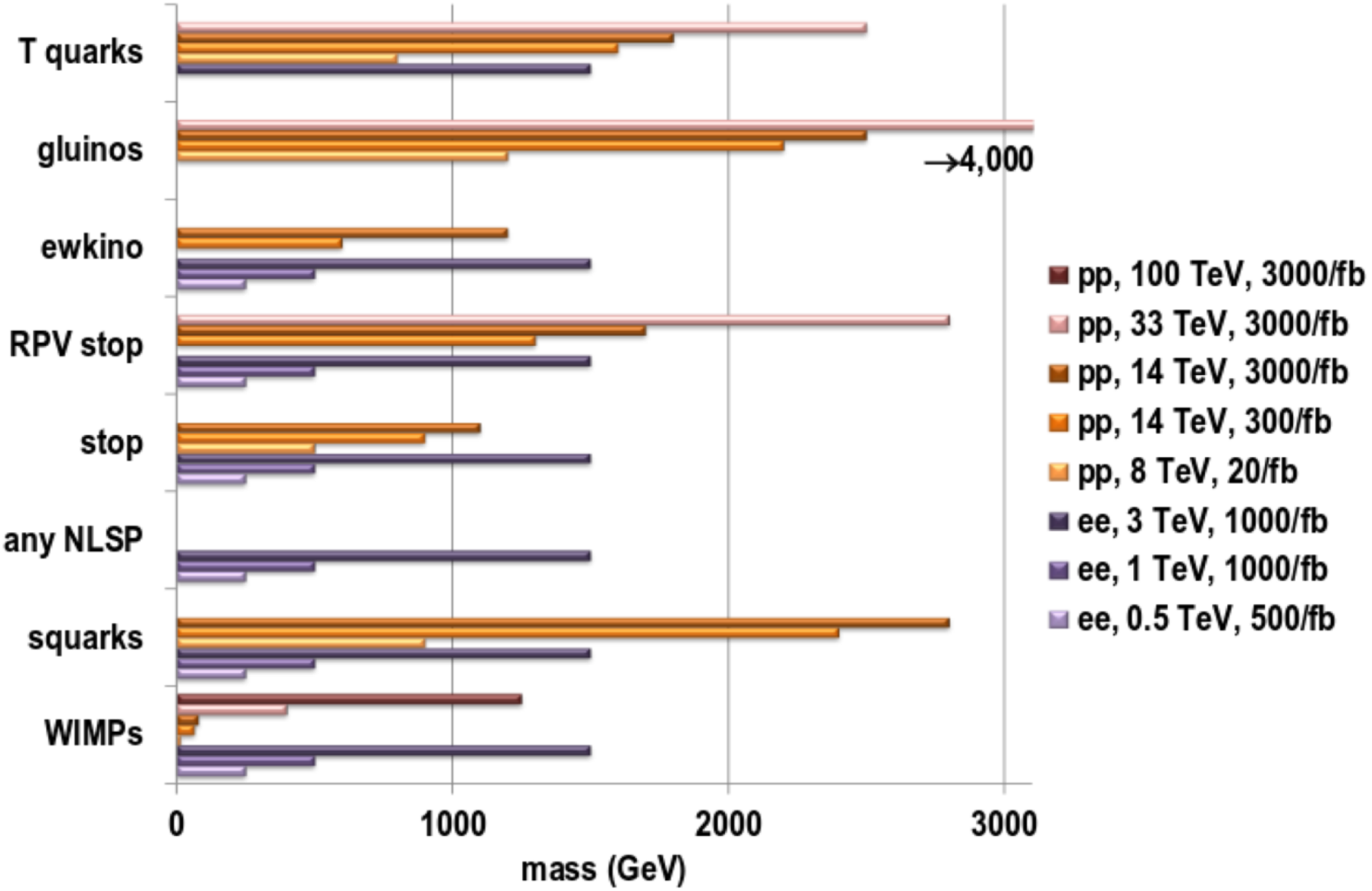
Reviving the VLHC discussion

http://vlhc.org/vlhc/

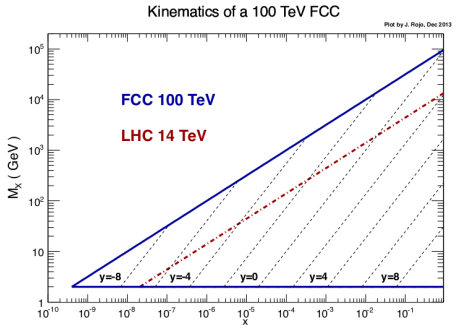


Snowmass 2013

Reach for New Particles



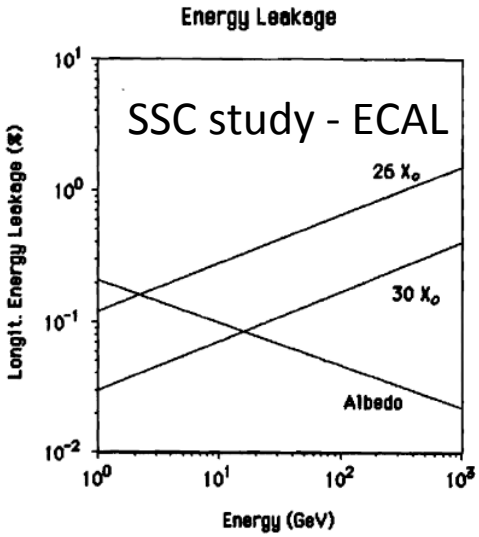
Some of the Key Issues



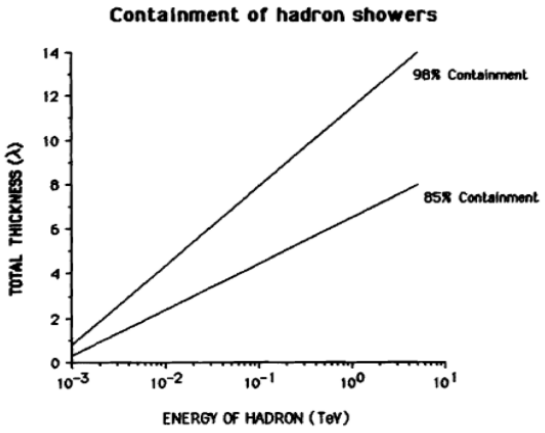
- PDFs:
  - Essentially no constraint for x < 10-4
  - Poor constraint for high x
  - PDF fits rely on QCD evolutions
    - EW effects will be needed for multi-TeV regions
    - Very important for electroweak (SUSY) production
- Hard Pile Up:
  - 171 (35) in-time pile-up events with 25 (5) ns bunch spacing
    - High-granularity calorimetry, tracking and vertexing required
    - Ultra fast detectors required (out-of time pile-up)
  - understand effect of neutrals
    - energy subtraction in calorimeters – would “rho” correction work ?
  - will current particle flow algorithms work – range – MeV->TeV or GeV->TeV?

Issues impacting detector designs

- Many of detection capabilities will need further studies
  - Very energetic charged particles, jets (muons upto 10s of TeV, jets close to 50 TeV)
    - Precise momentum measurement up to 10 TeV require large coil and tracker
    - Energy containment require thicker calorimeter
  - ECAL: "low energy leakage" as well as good segmentation
    - For ~ 0.1% leakage, the thickness of EM part ~ 30 radiation length
  - SSC studies shows for a 20 TeV Jet, several 1 TeV hadrons are produced
  - missing ET from neutrinos – use the fact that neutrino's radiate Ws? use leptons?
  - concept of jet – may need to be evaluated
    - interplay between - granularity of detector and perturbative QCD at 10 TeV scale needs to be understood.

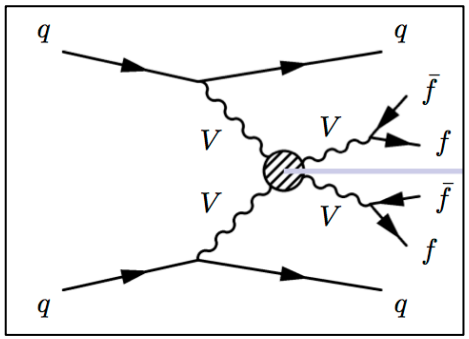


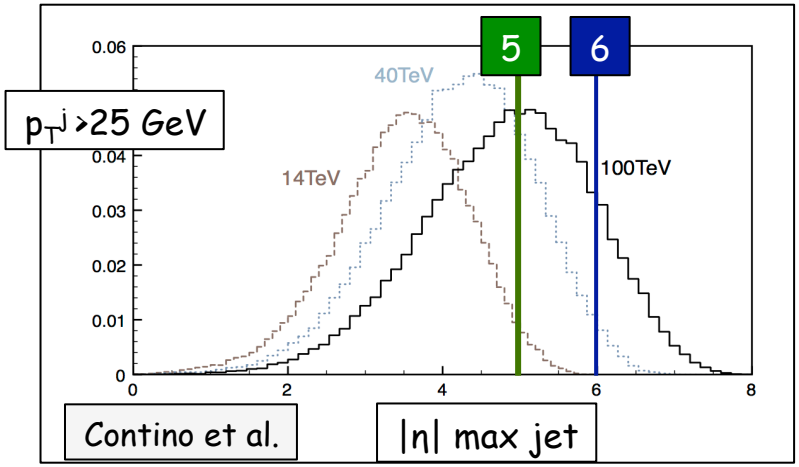
SSC study - HCAL



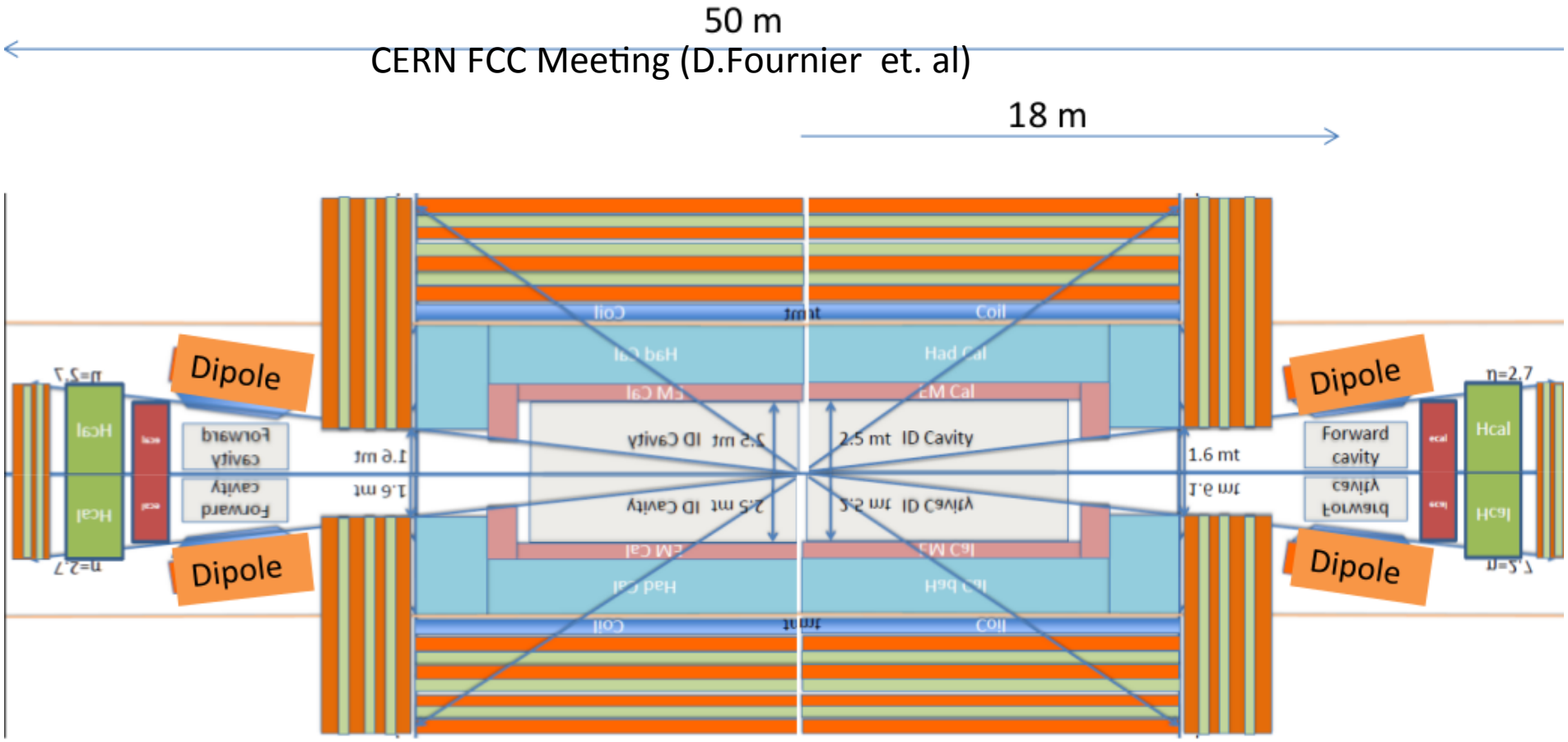
Issues impacting detector designs

- Boosted Objects
  - ability to resolve sub-jets efficiently, forward detectors in high radiation environments, etc.
  - current techniques need to re-evaluated
    - will impact the design / granularity of the calorimeters
    - Enhanced coverage at large rapidity required (tracking/calorimetry)
    - Also need for forward-jet tagging in boson fusion production
    - calorimeter coverage over $|\eta| \geq 6$ needed
  - Zs, Ws, Higgses, tops, will also be boosted
  - W/Z radiation within jets – unique!



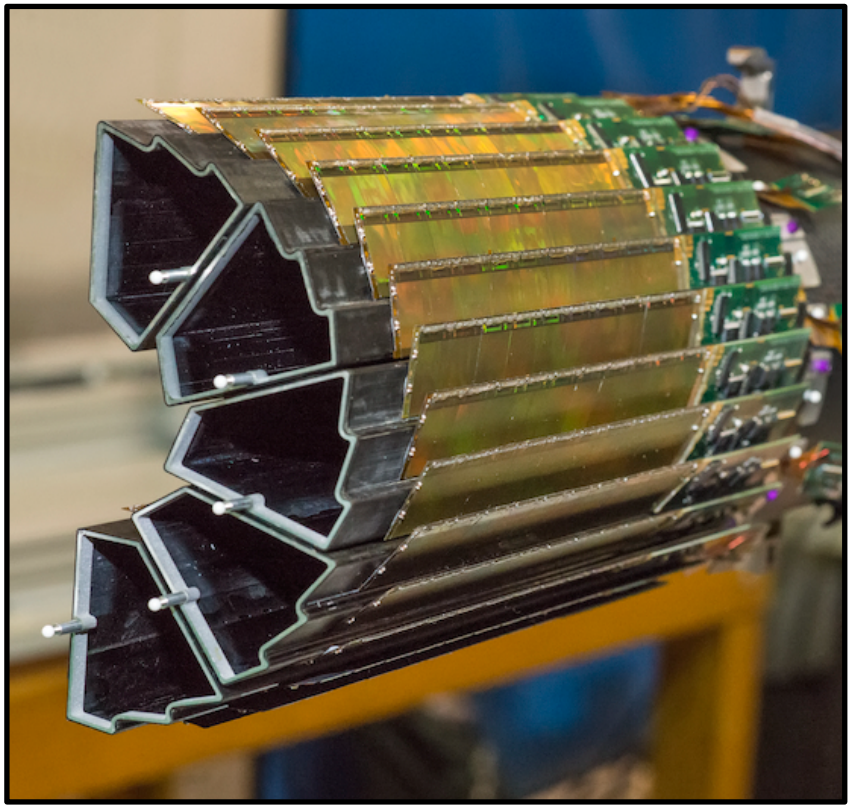


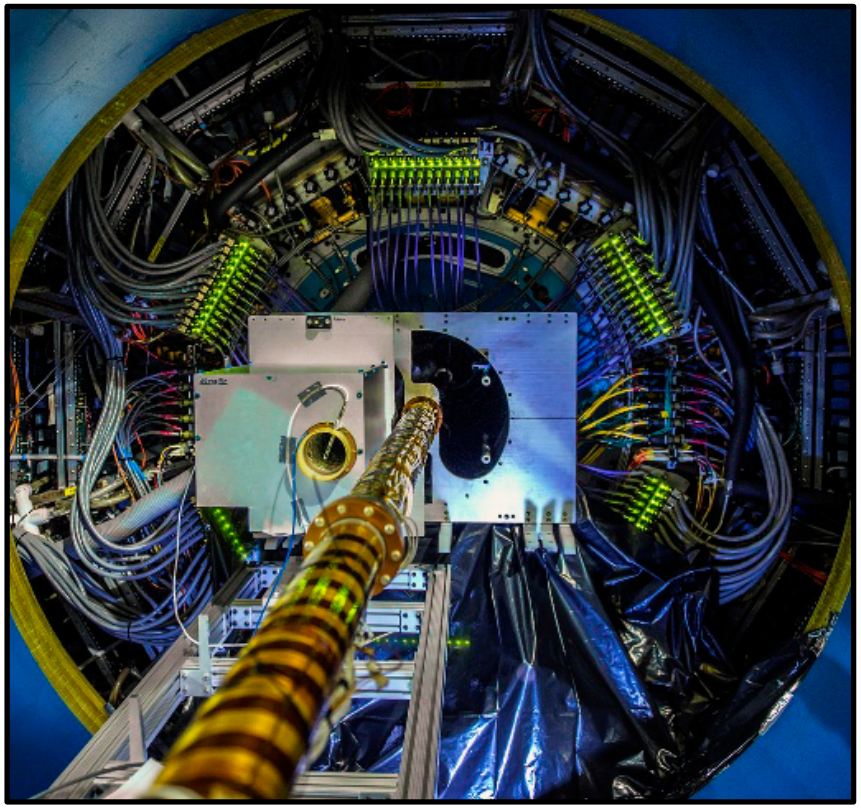
Approximate Detector



Tracker…

Need ultra-light, ultra-fast, ultra-granular, rad-hard, low-power Si trackers



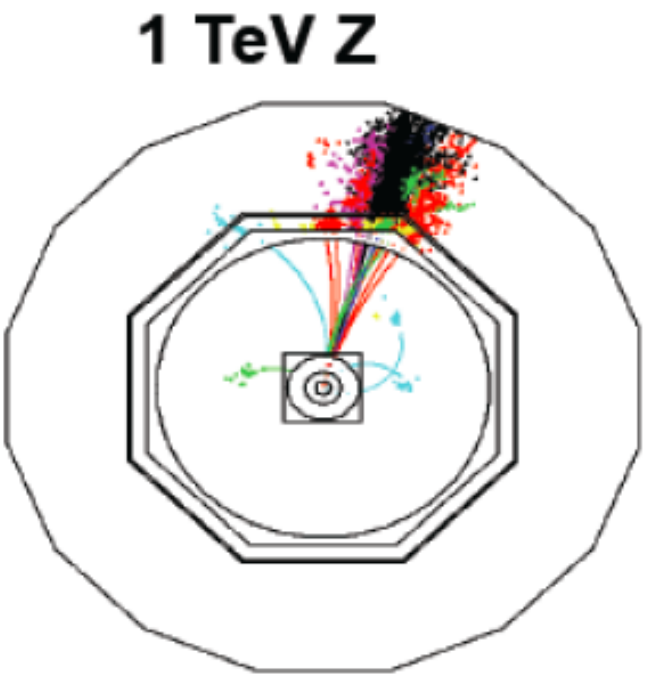


STAR CMOS Tracker

Rad-hard CMOS could revolutionise tracker technology?

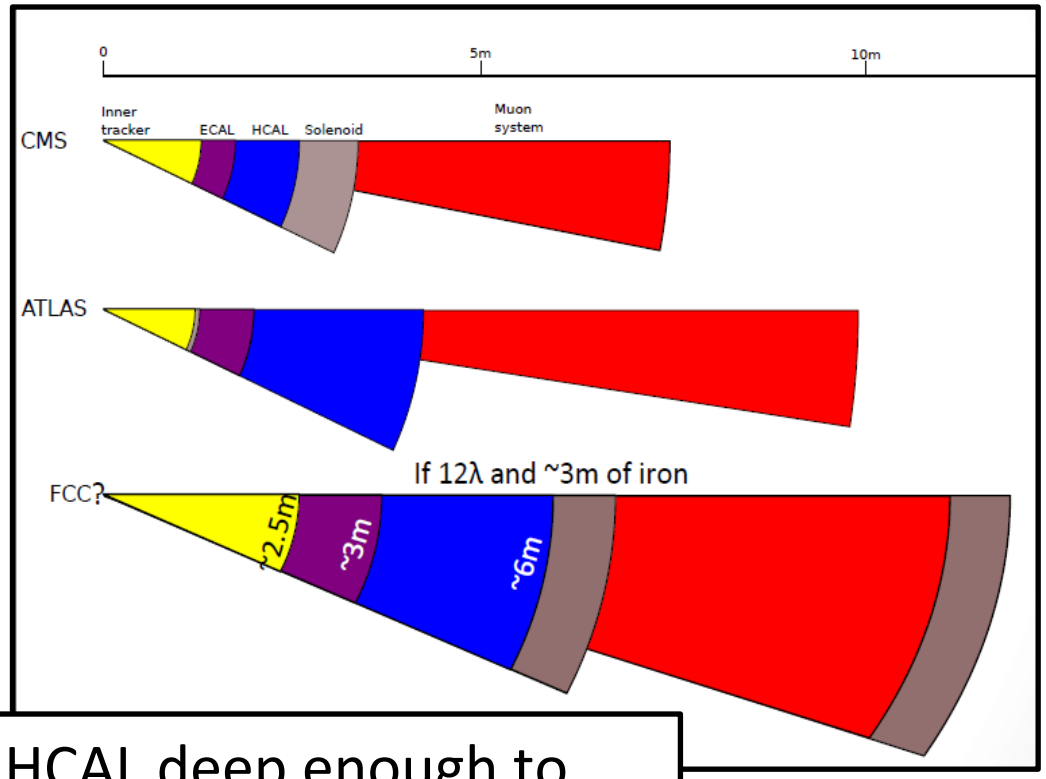
Calorimeter…

10^8 channel imaging calorimeters (power consumption and cooling at high-rate machines,..)



Tracking ECAL

$\Delta E/E \sim 16\%/\sqrt{E} \oplus 1.1\%$



HCAL deep enough to prevent punch-through

$\Delta E/E \sim 35\text{-}60\%/\sqrt{E} \oplus 3\%$

Clement Helsens, Steinar Stapnes: FCC workshop, CERN, May 2014

Global Efforts (in 2014)

- LPC@FNAL: January

LPC meeting on future 100 TeV proton collider

chaired by Sanjay Padhi (Univ. of California San Diego (US))

Friday, 31 January 2014 from **08:30** to **15:20** (America/Chicago)
at **Fermilab (Sunrise)**

- CERN: February

Future Circular Collider Study
Kickoff Meeting

12-15 February 2014
University of Geneva - UNI MAIL
Europe/Zurich timezone

Search

- SLAC: April

Workshop on Physics at a 100 TeV Collider

23-25 April 2014 *SLAC*
US/Pacific timezone

Chairs:
Cohen, Timothy
Hance, Mike
Wacker, Jay
Peskin, Michael
Arkani-Hamed, Nima

- Beijing: August

2nd CFHEP Symposium on circular collider physics

11-15 August 2014
IHEP
Asia/Shanghai timezone

Organizers:
Nima Arkani-Hamed, director (IAS)
Cai-Dian Lu, deputy director (IHEP)

"We (I) have a Dream"

- Synergy between various global efforts are essential.
- LPC welcomes you this week to join us in our continued dialogue to bring together various initiatives on how to advance the energy frontier, with emphasis on hadron colliders.
  - Many thanks to all of you for joining us from near and far !(especially during the prime vacation month!
- We invite you to visit the LPC (10^{th}, 11^{th} floors) for lively discussions with the best cup of coffee in town!
- The path to a next generation hadron collider is long
  - *Let's make it technically achievable*
  - *Let's keep our passion for science*
  - *Let's follow our dreams!*

thank you

- to all from whom I have shamelessly borrowed…

- interesting talks/websites
- S. Padhi (CFHEP): http://indico.ihep.ac.cn/getFile.py/access?contribId=4&resId=0&materialId=slides&confId=4068
- LHC: http://home.web.cern.ch/topics/large-hadron-collider
- HL-LHC: http://hilumilhc.web.cern.ch/HiLumiLHC/index.html
- CMS: http://cms.web.cern.ch/
- ATLAS: http://atlas.ch/
- SppC: http://cfhep.ihep.ac.cn/
- FCC: https://espace2013.cern.ch/fcc/[illegible]aspx